WJEC Biology A-level

Topic 2.3: Adaptations for transport

Notes

Circulatory systems can either be **open**, for instance in insects or **closed**, like in fish and mammals where the blood is confined to blood vessels only. Closed circulatory systems come in two forms, either a **single** form which consists of a heart with **two chambers** meaning the blood passes through the heart **once for every circuit** of the body or **double**, where the heart has **four chambers** and blood passes through the heart **twice for every circuit** of the body.

Important structures and their functions

- **Arteries** – adapted to carrying blood away from the heart to the rest of the body, thick walled to withstand high blood pressure, contain elastic tissue which allows them to stretch and recoil thus smoothing blood flow, contain smooth muscle which enables them to vary blood flow, lined with smooth endothelium to reduce friction and ease the flow of blood.

- **Arterioles** – branch off arteries, have thinner and less muscular walls, their role is to feed blood into capillaries.

- **Capillaries** – smallest blood vessels, site of metabolic exchange, only one cell thick for fast exchange of substances.

- **Venules** – larger than capillaries but smaller than veins.

- **Veins** – carry blood from the body to the heart, contain wide lumen to maximum volume of blood carried to the heart, thin walled as blood is under low pressure, contain valves to prevent backflow of blood, no pulse of blood meaning there's little elastic tissue or smooth muscle as there is no need for stretching and recoiling.

Tissue fluid is a liquid containing **dissolved oxygen and nutrients** which serves as a means of supplying the tissues with the essential solutes in exchange for waste products such as carbon dioxide. Therefore, it enables **exchange of substances** between blood and cells.

Hydrostatic pressure is created when blood is pumped along the arteries, into arterioles and then capillaries. This pressure forces blood fluid out of the capillaries. Only substances which are small enough to escape through the gap in capillary are components of the tissue fluid – this includes **dissolved nutrients and oxygen**. The fluid is referred to as tissue fluid, as described above.

The fluid is also acted on by **hydrostatic pressure** which pushes some of the fluid back into the capillaries. As both the tissue fluid and blood contain solutes, they have a **negative water potential**. However, the potential of tissue fluid is less negative therefore meaning that water moves down the water potential gradient from the tissue fluid to the blood by **osmosis.**

The remaining tissue fluid which is not pushed back into the capillaries is carried back via the **lymphatic system**. The lymphatic system contains **lymph fluid**, similar in content to tissue fluid. However, lymph fluid contains **less oxygen and nutrients** compared to tissue fluid, as its main purpose is to **carry waste products.** The lymph system also contains **lymph nodes** which filter out **bacteria and foreign material** from the fluid with the help of l**ymphocytes** which destroy the invaders as part of the **immune system defences.**

Mammalian heart and cardiac cycle

Due to the heart's ability to initiate its own contraction, it is referred to as **myogenic**. In the wall of the right atrium there is a region of specialised fibres called the **sinoatrial node** which is the **pacemaker** of the heart, as it initiates a wave of electrical stimulation which causes the atria to contract at roughly the same time. The ventricles do not start contracting until the atria have finished due to the presence of tissue at the base of the atria which is unable to conduct the wave of excitation. The electrical wave eventually reaches the **atrioventricular node** located between the two atria which passes on the excitation to ventricles, down the **bundle of His to the apex** of the heart. The bundle of His branches into **Purkyne fibres** which carry the wave upwards. This causes the ventricles to contract, thus emptying them.

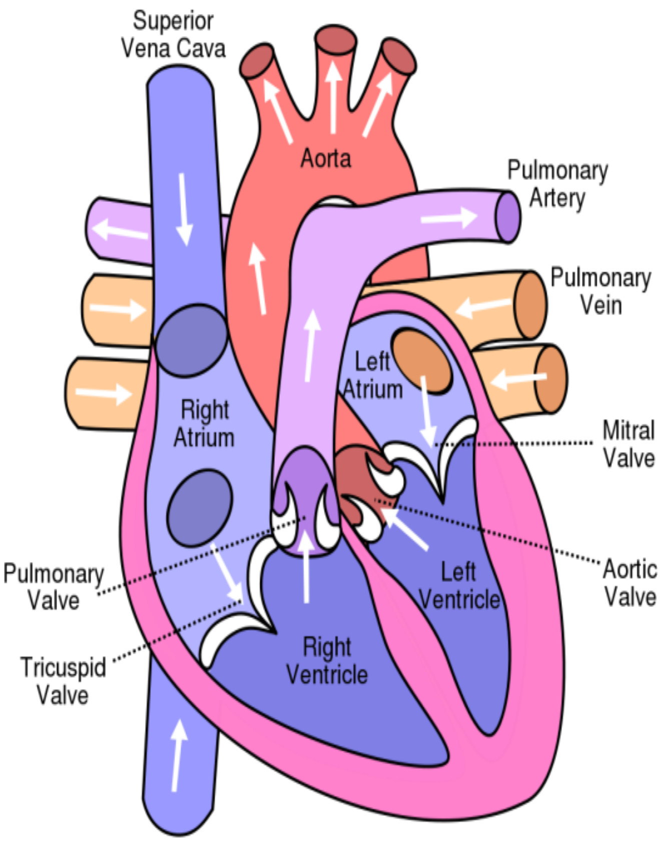


Figure SEQ Figure * ARABIC 1 Wikipedia - Atrium

There are 3 stages of the cardiac cycle:

1) **Atrial systole** – during atrial systole the **atria contract** and this forces the atrio-ventricular **valves open** and blood flows into the ventricles.

2) **Ventricular systole – contraction of the ventricles** causes the **atrio-ventricular valves** to **close** and **semi-lunar valves to open** thus allowing **blood to leave the left** ventricle through the **aorta** and right ventricle through the **pulmonary artery**.

3) **Cardiac diastole** – atria and ventricles relax, **elastic recoil** of the heart **lowers the pressure inside the heart chambers** and **blood is drawn from the arteries and veins** thus causing **semilunar valves** in the aorta and pulmonary arteries to close, preventing backflow of blood.

Haemoglobin

Haemoglobin is a **water soluble globular protein** which consists of **two beta polypeptide chains and a haem group**. It **carries oxygen** in the blood as oxygen can bind to the haem (Fe2+) group and oxygen is then released when required. Each molecule can carry four oxygen molecules.

The **affinity of oxygen for haemoglobin** varies depending on the partial pressure of oxygen which is a measure of **oxygen concentration**. The greater the concentration of dissolved oxygen in cells the greater the partial pressure. Therefore, as **partial pressure** increases, the affinity of haemoglobin for oxygen increases, that is oxygen binds to haemoglobin tightly. This occurs in the lungs in the process known as loading. During **respiration**, oxygen is used up therefore the partial pressure decreases, thus decreasing the affinity of oxygen for haemoglobin. As a result of that, oxygen is released in respiring tissues where it is needed. After the unloading process, the haemoglobin returns to the lungs where it binds to oxygen again.

Dissociation curves illustrate the change in haemoglobin saturation as partial pressure changes. The saturation of haemoglobin is affected by its affinity for oxygen, therefore in the case where partial pressure is high, haemoglobin has high affinity for oxygen and is therefore highly saturated, and vice versa.

Saturation can also have an effect on affinity, as after binding to the first oxygen molecule, the affinity of haemoglobin for oxygen increases due to a change in shape, thus making it easier for the other oxygen molecules to bind.

Fetal heamoglobin has a different affinity for oxygen compared to **adult haemoglobin**, as in needs to be better at absorbing oxygen because by the time oxygen reaches the placenta, the oxygen saturation of the blood has decreased. Therefore, fetal haemoglobin must have a **higher affinity for oxygen** in order for the foetus to survive at low partial pressure.

The affinity of haemoglobin for oxygen is also affected by the **partial pressure of carbon dioxide**. Carbon dioxide is released by **respiring cells** which require oxygen for the process to occur. Therefore, in the presence of carbon dioxide, the affinity of haemoglobin for oxygen decreases, thus causing it to be released. This is known as the **Bohr effect.**

The vascular bundle

The vascular bundle in the roots:

- Xylem and phloem are components of the **vascular bundle**, which serves to enable transport of substances as well as for structural support.
- The xylem vessels are arranged in an **X shape** in the centre of the vascular bundle. This enables the plant to withstand various **mechanical forces** such as pulling.
- The X shape arrangement of xylem vessels is surrounded by **endodermis**, which is an outer layer of cells which supply xylem vessels with water.
- An inner layer of meristem cells known as the **pericycle**

The vascular bundle in the stem:

- Xylem is located on the inside in **non-wooded plants** to provide support and flexibility to the stem
- Phloem is found on the outside of the vascular bundle
- There is a layer of **cambium** in between xylem and phloem, that is meristem cells which are involved in the production of new xylem and phloem tissue

The vascular bundle in the leaf:

- The vascular bundles form the **midrib and veins** of a leaf
- **Dicotyledonous leaves** have a network of **veins**, starting at the midrib and spreading outwards which are involved in transport and support

Xylem and phloem

Xylem vessels have the following features:

- They transport water and minerals, and also serve to provide structural support
- They are long cylinders made of **dead tissue** with **open ends**, therefore they can form a continuous column.
- Xylem vessels also contain pits which enable water to more sideways between the vessels.
- They are thickened with a tough substance called lignin, which is deposited in **spiral patterns** to enable the plant to remain flexible

The features of phloem vessels include:

- They're tubes made of **living cells**
- Involved in **translocation** which is the movement of nutrients to storage organs and growing parts of the plant
- Consist of **sieve tube elements** and **companion cells**
- Sieve tube elements form a tube to transport sugars such as sucrose, in the dissolved form of sap

- Companion cells are involved in **ATP production** for active processes such as loading sucrose into sieve tubes
- Cytoplasm of sieve tube elements and companion cells is linked through structures known as **plasmodesmata** which are gaps between cell walls which allow communication and flow of substances such as minerals between the cells

Transpiration

Transpiration is the process where plants absorb water through the roots, which then moves up through the plant and is released into the atmosphere as water vapour through pores in the leaves. Carbon dioxide enters, while water and oxygen exit through a leaf's stomata.

The **transpiration stream,** which is the movement of water up the stem enables processes such as photosynthesis, growth and elongation as it supplies the plant with water which is necessary for all these processes. Apart from this, the transpiration stream supplies the plant with the required minerals, whilst enabling it to control its temperature via evaporation of water.

Transpiration involves **osmosis**, where water moves from the xylem to the **mesophyll cells**. Transpiration also involves **evaporation** from the surface of mesophyll cells into intercellular spaces and diffusion of water vapour down a water vapour potential gradient out of the stomata.

The rate of transpiration can be investigated with the help of a **potometer** where water lost by the leaf is replaced by water in the capillary tube. Therefore, measuring the movement of the meniscus can be used to determine the rate of transpiration. Factors which affect the rate of transpiration include **number of leaves, number/size or position of stomata, presence of waxy cuticle, the amount of light present, the temperature, humidity, air movement and water availability.**

Xerophytes are plants adapted to living in **dry conditions**. They are able to survive in such conditions because of various adaptations which serve to **minimise the water loss**. The adaptations include smaller leaves which reduce the surface area for water loss. Both densely packed mesophyll and thick waxy cuticle to prevent water loss via evaporation. Moreover, xerophytes respond to low water availability by closing the stomata to prevent water loss. Apart from this, they contain hairs and pits which serve as a means of trapping moist air, thus reducing the water vapour potential. Xerophytes also roll the leaves to reduce the exposure of lower epidermis to the atmosphere, thus trapping air.

Movement of water in the root

Water enters through the root **hair cells** and moves into the xylem tissue located in the centre of the root. This movement occurs as a result of **a water potential gradient**, as the water potential is higher inside the soil than inside the root hair cells, due to the dissolved substances in the **cell sap.**

Therefore, the purpose of **root hair cells** it to provide a large surface area for the movement of water to occur.

Minerals are also absorbed through the root hair cells by **active transport**, as they need to be pumped against the concentration gradient.

There are two ways the water taken up by the root hair cells can move across the cortex of the root into xylem:

- It can either occur via the **symplast pathway** where water enters the cytoplasm through the plasma membrane and passes from one cell to the next through plasmodesmata, the channels which connect the cytoplasm of one cell to the next.
- The other pathway is the **apoplast pathway** where the water moves through the water filled spaces between cellulose molecules in the cell walls. In this pathway, water doesn't pass through any plasma membranes therefore it can carry dissolved mineral ions and salts.
- When the water reaches a part of the root called the endodermis, it encounters a layer of suberin which is known as the **Casparian strip,** which cannot be penetrated by water.
- Therefore, in order for the water to cross the **endodermis,** the water that has been moving through the cell walls must now enter the symplast pathway.
- Once it has moved across the endodermis, the water continues down the water potential gradient from cell to cell until it reaches a pit in the xylem vessel which is the entry point of water.

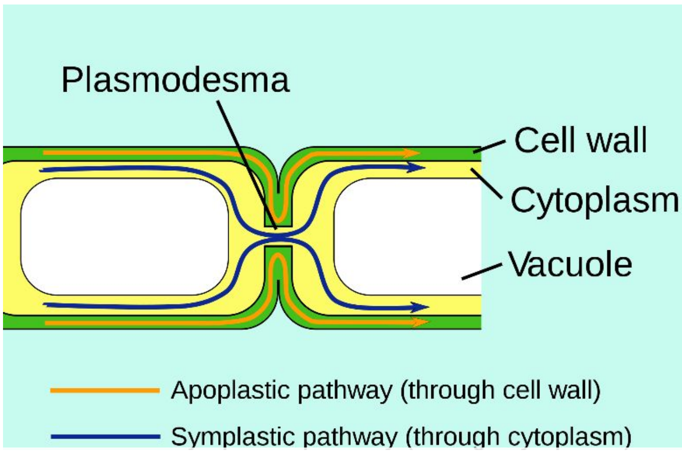


*Figure SEQ Figure * ARABIC 1 Wikipedia - Symplast*

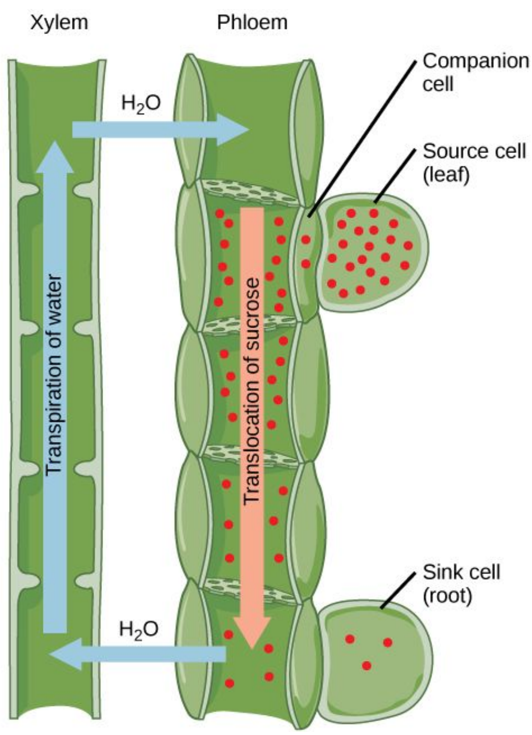
Water moving in the xylem up the stem

The water is removed from the top of the xylem vessels into the mesophyll cells down the **water potential gradient.** The push of water upwards is aided by the **root pressure** which is where the action of the endodermis moving minerals into the xylem by **active transport,** drives water into the xylem by osmo**sis**, thus pushing it upwards.

The flow of water is also maintained with the help of **surface tension** of water and the attractive forces between water molecules known as **cohesion**. The action of these two forces in combination is known as the **tension-cohesion theory**, which is further supported by **capillary action** where the forces involved in cohesion cause the water molecule to adhere to the walls of xylem, thus pulling water up.

Translocation

Translocation is an energy requiring process which serves as a means of transporting assimilates such as sucrose in the phloem between sources which release sucrose such as leaves and sinks e.g. roots and meristem which remove sucrose from the phloem.



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Sucrose enters the phloem in a process known as **active loading** where companion cells use ATP to transport hydrogen ions into the surrounding tissue, thus creating a **diffusion gradient,** which causes the H+ ions to diffuse back into the companion cells. It is a form of **facilitated diffusion** involving cotransporter proteins which allows the returning H+ ions to bring sucrose molecules into the companion cells, thus causing the concentration of sucrose in the companion cells to increase. As a result of that, the sucrose diffuses out of the companion cells down the **concentration gradient** into the sieve tube elements through links known as **plasmodesmata**.

As sucrose enters the sieve tube elements, the **water potential** inside the tube is reduced, therefore causing water to enter via **osmosis,** as a result increasing the **hydrostatic pressure** of the sieve tube. Therefore, water moves down the sieve tube from an area of higher pressure to an area of lower pressure. Eventually, sucrose is removed from the sieve tube elements by diffusion or active transport into the surrounding cells, thus increasing the water potential in the sieve tube. This in turn means that water leaves the sieve tube by osmosis, as a result **reducing the pressure in the phloem at the sink.**

Therefore, in summary the mass flow of water from the source to the sink down the **hydrostatic pressure gradient** is a means of supplying assimilates such as sucrose to where they are needed.